

WHAT IS CLAIMED IS:

1 1. A hearing aid, comprising:
2 an input signal channel providing digital input signals;
3 a signal path adapted to process said digital input signals in accordance
4 with a predetermined signal processing algorithm to produce a digital output signal,
5 wherein said signal path further comprises at least one signal processing function
6 operating on a warped frequency scale, and wherein said at least one signal processing
7 function includes at least one spectral enhancement algorithm; and
8 an output conversion means adapted to convert said output signals to an
9 audio output.

1 2. The hearing aid of claim 1, wherein said at least one signal
2 processing function further comprises a plurality of cascaded all-pass filters.

1 3. The hearing aid of claim 1, wherein said warped frequency scale
2 approximates a Bark scale.

1 4. A frequency-warped processing system, comprising:
2 an input signal channel providing digital input signals;
3 a plurality of cascaded all-pass filters, wherein said digital input signals
4 pass through said plurality of cascaded all-pass filters, and wherein said plurality of
5 cascaded all-pass filters output a sequence of delayed samples;
6 means for applying a frequency domain transform on said sequence of
7 delayed samples, wherein a warped sequence results from said frequency domain
8 transform applying means;
9 means for calculating a plurality of frequency domain level estimates from
10 said warped sequence;
11 means for calculating a plurality of frequency domain gain coefficients
12 from said plurality of frequency domain level estimates;
13 means for calculating a plurality of spectral enhancement gain coefficients
14 from said warped sequence;

15 means for calculating a plurality of compression-spectral enhancement
16 gain coefficients from said plurality of frequency domain gain coefficients and said
17 plurality of spectral enhancement gain coefficients;

18 means for applying an inverse frequency domain transform on said
19 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
20 domain filter coefficients of a compression gain filter result from said inverse frequency
21 domain transform applying means; and

22 means for convolving said sequence of delayed samples with said set of
23 time-domain filter coefficients to produce a digital output signal.

1 5. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a
4 power spectrum comprised of said plurality of frequency domain level estimates to a
5 power greater than 1.

1 6. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies
4 a plurality of peaks of said warped sequence.

1 7. The frequency-warped processing system of claim 6, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 8. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes
4 means for forming an unsmeared warped sequence, and means for calculating the
5 difference between said warped sequence and said unsmeared warped sequence.

1 9. The frequency-warped processing system of claim 4, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 10. The frequency-warped processing system of claim 4, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 11. The frequency-warped processing system of claim 4, further
2 comprising means for windowing said sequence of delayed samples, wherein a windowed
3 sequence of delayed samples results from said windowing means, and wherein said
4 warped sequence results from applying said frequency domain transform to said
5 windowed sequence of delayed samples.

1 12. The frequency-warped processing system of claim 4, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 13. The frequency-warped processing system of claim 12, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 14. The frequency-warped processing system of claim 4, said plurality
2 of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 15. The frequency-warped processing system of claim 4, said sequence
2 of delayed samples comprising 16 samples.

1 16. The frequency-warped processing system of claim 4, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 frequency domain transform applying means, said frequency domain level estimates
4 calculating means, said frequency domain gain coefficients calculating means, said
5 spectral enhancement gain coefficients calculating means, said inverse frequency domain
6 transform applying means, and said means for convolving said sequence of delayed
7 samples.

1 17. The frequency-warped processing system of claim 16, wherein said
2 digital processor comprises a software programmable digital signal processor.

1 18. The frequency-warped processing system of claim 4, wherein said
2 frequency domain transform applying means uses a transform selected from the group

3 consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel transforms,
4 and discrete cosine transforms.

1 19. The frequency-warped processing system of claim 4, further
2 comprising:

3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 20. The frequency-warped processing system of claim 4, further
2 comprising:

3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and

5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 21. A frequency-warped processing system, comprising:

2 an input signal channel providing digital input signals;

3 an input data buffer, said input data buffer holding at least one block of
4 data comprised of a portion of said digital input signals;

5 a plurality of cascaded all-pass filters, wherein a first block of said digital
6 input signals pass from said input data buffer through said plurality of cascaded all-pass
7 filters, and wherein said plurality of cascaded all-pass filters output a first sequence of
8 delayed samples;

9 means for windowing a first portion of said first sequence of delayed
10 samples, wherein a first windowed sequence of delayed samples results from said
11 windowing means;

12 means for applying a first frequency domain transform on said first
13 windowed sequence of delayed samples, wherein a first warped sequence results from
14 said first frequency domain transform applying means;

15 means for calculating a first plurality of frequency domain level estimates
16 of said first warped sequence;

17 means for calculating a first plurality of spectral enhancement gain
18 coefficients from said first warped sequence;

19 means for windowing a second portion of said first sequence of delayed
20 samples, wherein a second windowed sequence of delayed samples results from said
21 windowing means;
22 means for applying a second frequency domain transform on said second
23 windowed sequence of delayed samples, wherein a second warped sequence results from
24 said second frequency domain transform applying means;
25 means for calculating a second plurality of frequency domain level
26 estimates of said second warped sequence;
27 means for calculating a first plurality of spectral enhancement gain
28 coefficients from said first warped sequence;
29 means for summing said first and second plurality of spectral enhancement
30 gain coefficients, wherein a summed first and second plurality of spectral enhancement
31 gain coefficients results from said summing means;
32 means for summing said first and second plurality of frequency domain
33 level estimates, wherein a summed first and second plurality of frequency domain level
34 estimates results from said summing means;
35 means for normalizing said summed first and second plurality of frequency
36 domain level estimates, wherein a normalized first and second plurality of frequency
37 domain level estimates results from said normalizing means;
38 means for calculating a plurality of frequency domain gain coefficients
39 from said normalized first and second plurality of frequency domain level estimates;
40 means for calculating a plurality of compression-spectral enhancement
41 gain coefficients from said plurality of frequency domain gain coefficients and said
42 summed first and second plurality of spectral enhancement gain coefficients;
43 means for applying an inverse frequency domain transform on said
44 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
45 domain filter coefficients of a compression gain filter result from said inverse frequency
46 domain transform applying means; and
47 means for convolving a second sequence of delayed samples with said
48 time-domain filter coefficients, said second sequence of delayed samples produced by a
49 second block of said digital input signals passing from said input data buffer through said
50 plurality of cascaded all-pass filters, wherein a digital output signal results from said
51 convolving means.

1 22. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm raises a power spectrum comprised of said plurality of frequency domain level
5 estimates to a power greater than 1.

1 23. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm amplifies a plurality of peaks of said warped sequence.

1 24. The frequency-warped processing system of claim 23, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 25. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm includes means for forming an unsmeared warped sequence, and means for
5 calculating the difference between said warped sequence and said unsmeared warped
6 sequence.

1 26. The frequency-warped processing system of claim 21, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 27. The frequency-warped processing system of claim 21, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 28. The frequency-warped processing system of claim 21, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 29. The frequency-warped processing system of claim 28, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 30. The frequency-warped processing system of claim 21, said
2 plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 31. The frequency-warped processing system of claim 21, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 windowing means, said means for applying said first and second frequency domain
4 transforms, said means for calculating said first and second plurality of frequency domain
5 level estimates, said summing means, said normalizing means, said frequency domain
6 gain coefficients calculating means, said inverse frequency domain transform applying
7 means, and said convolving means.

1 32. The frequency-warped processing system of claim 21, wherein said
2 means for applying said first and second frequency domain transforms use a transform
3 selected from the group consisting of discrete Fourier transforms, fast Fourier transforms,
4 Goertzel transforms, and discrete cosine transforms.

1 33. The frequency-warped processing system of claim 21, further
2 comprising:
3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and
5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 34. The frequency-warped processing system of claim 21, further
2 comprising:
3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and
5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 35. The frequency-warped processing system of claim 21, wherein said
2 windowing means provides a 50 percent overlap of said first and second pluralities of
3 frequency domain level estimates.

1 36. The frequency-warped processing system of claim 21, wherein a
2 quantity of samples corresponding to said first block of said digital input signals is
3 equivalent to a quantity of first order all-pass filters corresponding to said plurality of
4 cascaded all-pass filters.

1 37. The frequency-warped processing system of claim 36, wherein said
2 first portion of said first sequence of delayed samples is comprised of a first half of said
3 first sequence of delayed samples and said second portion of said first sequence of
4 delayed samples is comprised of a second half of said first sequence of delayed samples.

1 38. A frequency-warped processing system, comprising:
2 an input signal channel providing digital input signals;
3 an input data buffer, said input data buffer holding a block of data of size
4 M comprised of a portion of said digital input signals;
5 a plurality of cascaded all-pass filters comprised of $2M$ cascaded all-pass
6 filters, wherein a first block of said digital input signals pass from said input data buffer
7 through said plurality of cascaded all-pass filters to form a first sequence of delayed
8 samples and wherein a second block of said digital input signals pass from said input data
9 buffer through said plurality of cascaded all-pass filters to form a second sequence of
10 delayed samples, and wherein said first sequence of delayed samples and said second
11 sequence of delayed samples form a combined sequence of delayed samples;
12 means for windowing a first portion of said combined sequence of delayed
13 samples, wherein said first portion is of size M , wherein a windowed sequence of delayed
14 samples results from said windowing means;
15 means for applying a $2M$ -point frequency domain transform on said
16 windowed sequence of delayed samples, wherein a warped sequence results from said
17 frequency domain transform applying means;
18 means for calculating a plurality of frequency domain level estimates of
19 said warped sequence;

20 means for calculating a plurality of frequency domain gain coefficients
21 from said plurality of frequency domain level estimates;
22 means for calculating a plurality of spectral enhancement gain coefficients
23 from said warped sequence;
24 means for calculating a plurality of compression-spectral enhancement
25 gain coefficients from said plurality of frequency domain gain coefficients and said
26 plurality of spectral enhancement gain coefficients;
27 means for applying an inverse frequency domain transform on said
28 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
29 domain filter coefficients of a compression gain filter result from said inverse frequency
30 domain transform applying means; and
31 means for convolving a second portion of said combined sequence of
32 delayed samples with said set of time-domain filter coefficients, wherein said second
33 portion is of size M, wherein a digital output signal results from said convolving means.

1 39. The frequency-warped processing system of claim 38, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a
4 power spectrum comprised of said plurality of frequency domain level estimates to a
5 power greater than 1.

1 40. The frequency-warped processing system of claim 38, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies
4 a plurality of peaks of said warped sequence.

1 41. The frequency-warped processing system of claim 40, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 42. The frequency-warped processing system of claim 38, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes

4 means for forming an unsmeared warped sequence, and means for calculating the
5 difference between said warped sequence and said unsmeared warped sequence.

1 43. The frequency-warped processing system of claim 38, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 44. The frequency-warped processing system of claim 38, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 45. The frequency-warped processing system of claim 38, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 46. The frequency-warped processing system of claim 45, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 47. The frequency-warped processing system of claim 38, said
2 plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 48. The frequency-warped processing system of claim 38, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 windowing means, said means for applying said 2M-point frequency domain transform,
4 said means for calculating said plurality of frequency domain level estimates, said
5 frequency domain gain coefficients calculating means, said inverse frequency domain
6 transform applying means, and said convolving means.

1 49. The frequency-warped processing system of claim 38, wherein said
2 means for applying said frequency domain transform uses a transform selected from the
3 group consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel
4 transforms, and discrete cosine transforms.

1 50. The frequency-warped processing system of claim 38, further
2 comprising:
3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and

5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 52. A signal processing system, comprising:

2 an input signal channel providing digital input signals;

means for calculating a power spectrum for said digital input signals;

means for applying a second difference operator to said power spectrum to
locate a plurality of power spectrum peaks;

means for amplifying said plurality of power spectrum peaks to achieve a modified power spectrum; and

means for producing a digital output signal from said modified power spectrum.

53. The signal processing system of claim 52, further comprising
means for determining the sharpness of each of said plurality of power spectrum peaks.

54. The signal processing system of claim 53, wherein said amplifying means applies a scaling factor to the amplification applied to each of said plurality of power spectrum peaks, said scaling factor based on the determined sharpness of the peak.

1 55. A method of processing sound in a hearing aid, comprising the
2 steps of

3 receiving digital input signals;

4 passing a portion of said digital input signals through a plurality of
5 cascaded all-pass filters to form a sequence of delayed samples;

6 windowing said sequence of delayed samples:

7 applying a frequency domain transform to said windowed sequence of
8 delayed samples to form a warped sequence;

9 calculating a plurality of frequency domain level estimates from said
10 warped sequence;
11 calculating a plurality of frequency domain gain coefficients from said
12 plurality of frequency domain level estimates to form a warped time-domain filter;
13 calculating a plurality of spectral enhancement gain coefficients from said
14 warped sequence;
15 calculating a plurality of compression-spectral enhancement gain
16 coefficients from said plurality of frequency domain gain coefficients and said plurality of
17 spectral enhancement gain coefficients;
18 applying an inverse frequency domain transform on said plurality of
19 compression-spectral enhancement gain coefficients to form a set of time-domain filter
20 coefficients; and
21 convolving said sequence of delayed samples with said set of time-domain
22 filter coefficients to produce a digital output signal.